An Analysis of Cleveland Center Route and Airspace Changes

Michael Drew

Michael Jastrzebski
University of California,
Santa Cruz

Karl Bilimoria
NASA Ames
Research Center

Mark Evans
Aviation Consultant
Dell Corporation

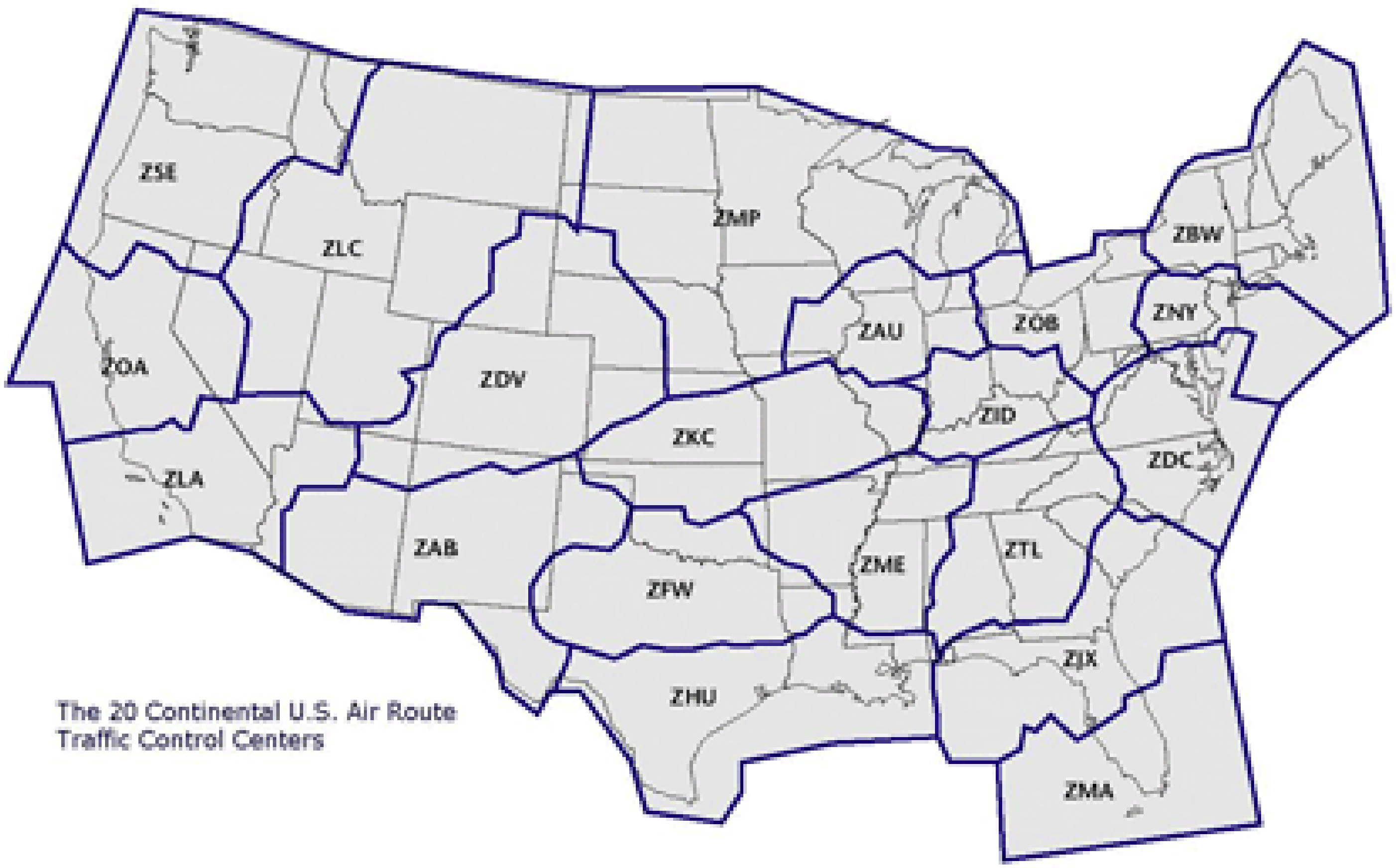
May 7, 2015

Outline

- Introduction
  - National Airspace System Description
  - TFM vs. DAC research
- Cleveland Center Analysis
  - Motivation
  - Data Collection
  - Airspace Metrics
  - Results
  - Conclusions

National Airspace System

- Airspace divided into imaginary partitions for monitoring and control
- 20 Air Route Traffic Control Centers (ARTCCs, or “Centers”) cover the continental US.

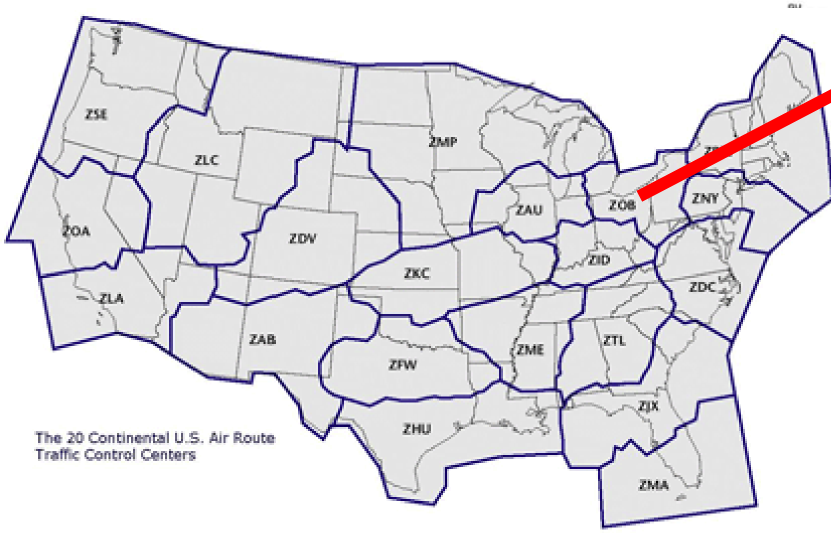


The 20 Continental U.S. Air Route Traffic Control Centers

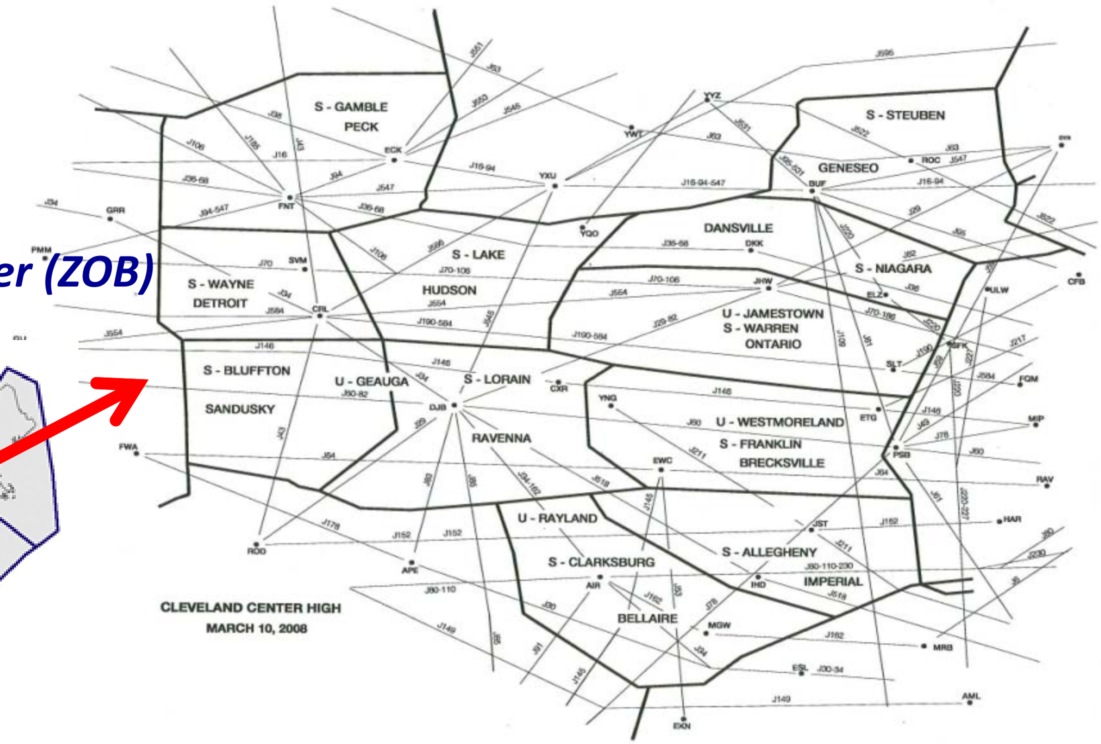
National Airspace System

- The airspace of each center is divided into dozens of smaller airspace partitions called Sectors

e.g. Cleveland Center (ZOB)



The 20 Continental U.S. Air Route Traffic Control Centers



National Airspace System

- Air traffic controllers work at control centers located within each center's airspace region
- 1-3 sectors monitored by 1-2 controllers

TFM vs. DAC Research

- Air Traffic Management (ATM) Research:
  - Find ways to decrease delay / increase throughput while maintaining safe operations
  - Constraints:
    - Safety
    - Weather
    - Environmental (noise, pollution)
    - Changing demand and airline operations
  - In former years, divided into TFM and DAC…

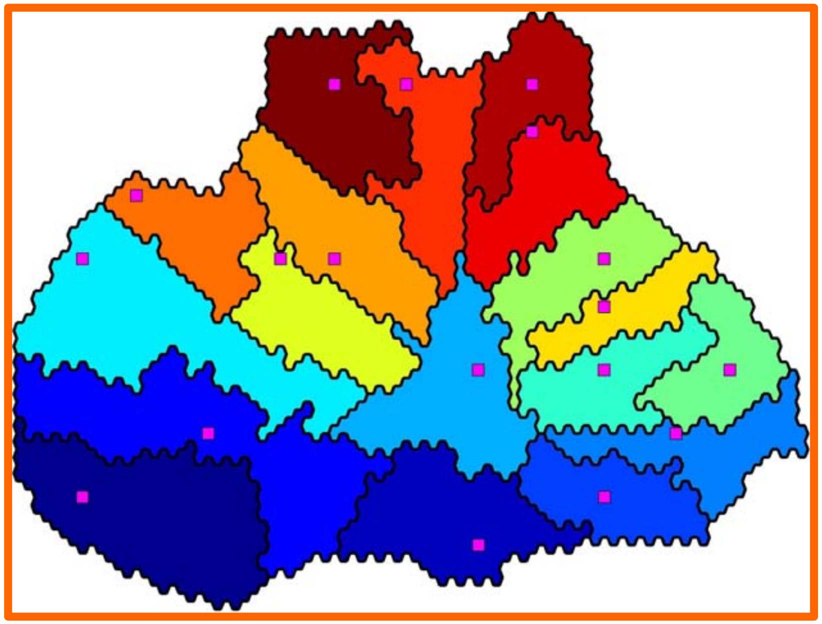
Traffic Flow Management (TFM)

- TFM Research: Can we develop tools and/or procedures to direct the traffic in a more efficient manner?
- TFM uses Traffic Management Initiatives (TMIs) when demand exceeds capacity
  - Traffic Management Units (TMUs) use several existing techniques for this:
    - Playbook re-routing
    - Miles-in-trail
    - Ground delay programs
    - Others

- Most ATM research is currently done in this area

Dynamic Airspace Configuration (DAC)

- Can we design the airspace (center, sectors, etc.) in a more efficient and systematic method?
- For example: Mixed Integer Linear Programming method of designing sectors:
- Research in DAC has declined, but many valuable tools and methods were developed
  - Richer understanding of ATC operational constraints
  - Quantifying ATC workload
  - Quantifying traffic complexity



Cleveland Center Analysis

- Motivation
- Data Collection
- Airspace Metrics
- Results
- Conclusions

Cleveland Center Analysis

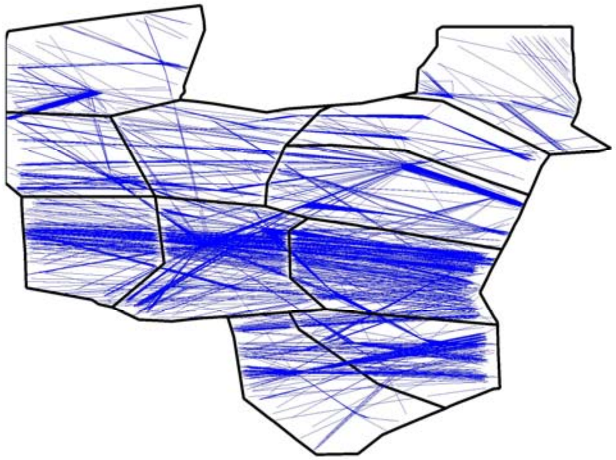
- Circa 2012 Cleveland Center proposed sector changes in response to routing changes.
- NASA was asked to validate/analyze those changes.

Existing Airspace & Routes
in Cleveland Center

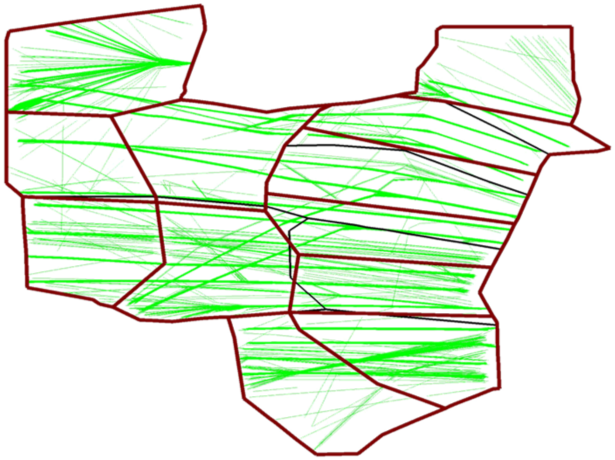
Proposed Sectors & Routes
in Cleveland Center

Motivation

- New York Center (to the east) transitioned to to using "Q-routes" in and out of New York to improve routing efficiency.
- High and ultra-high sectors were redesigned for better compatibility with the new Q-routes.



Existing Airspace & Routes
in Cleveland Center



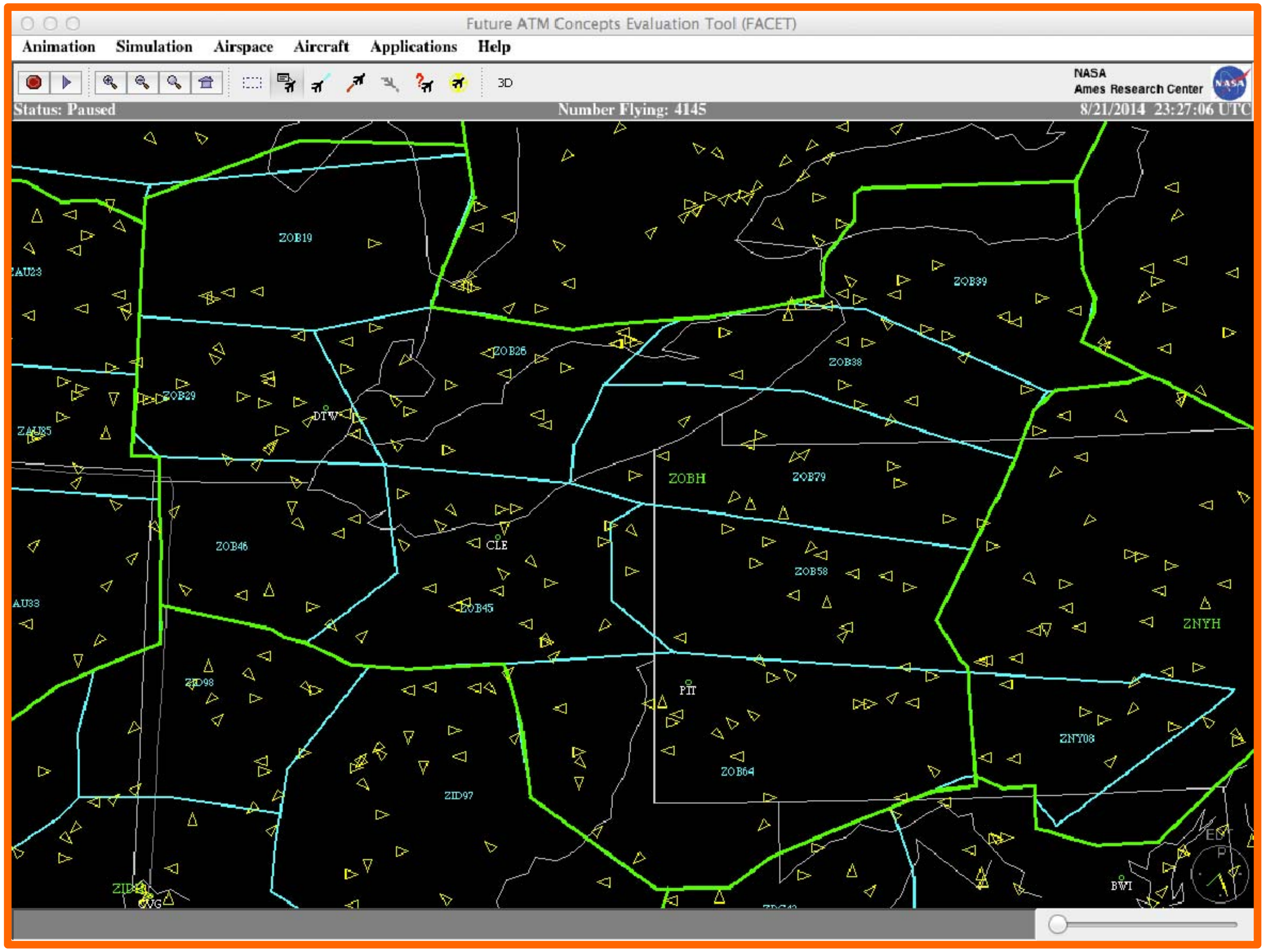
Proposed Sectors & Routes
in Cleveland Center

Data Collection

- Same simulated historical flight data used to analyze the performance of all scenarios
  - Based on historical filed flight plans
  - Simulation ignores flight plan updates, LOAs, controller interaction
- 30 high-volume days with estimated low weather-impact were selected from June 2012 – October 2012
- 6 am – 10 pm (EDT) each day
- Sector counts and workload factors are sampled every 60 seconds
- 29,000 data points per sector per factor

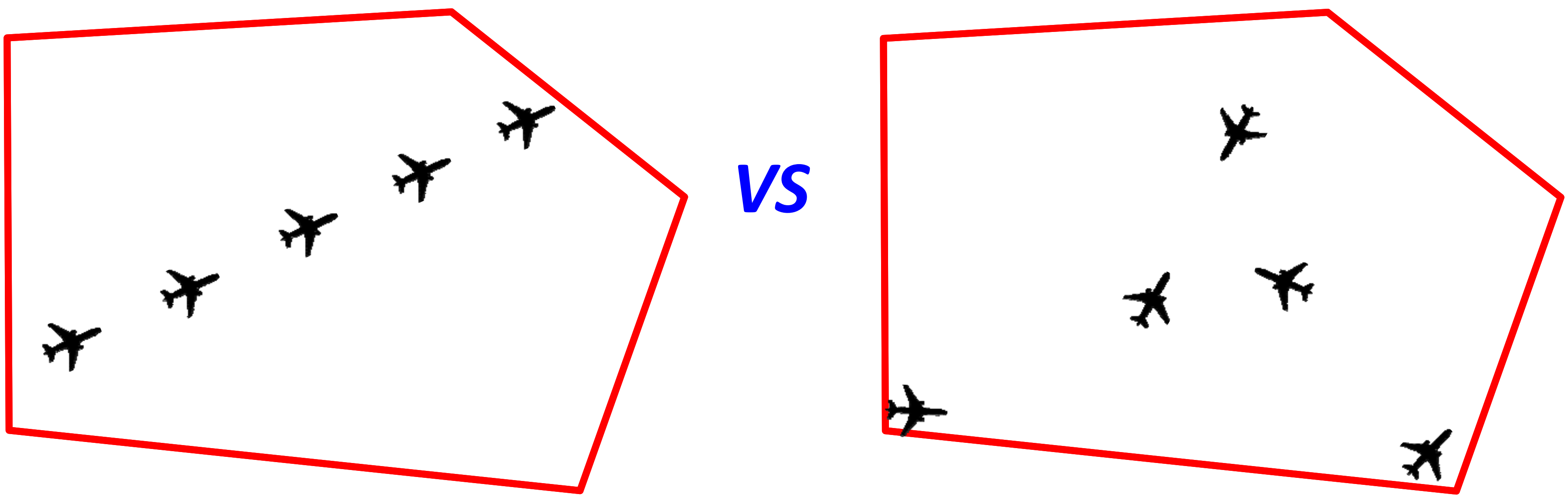
Airspace Metrics: Workload Factors

- FACET: Future ATM Concepts Evaluation Tool
  - Used to simulate and record flights in Cleveland Center



Airspace Metrics: Workload Factors

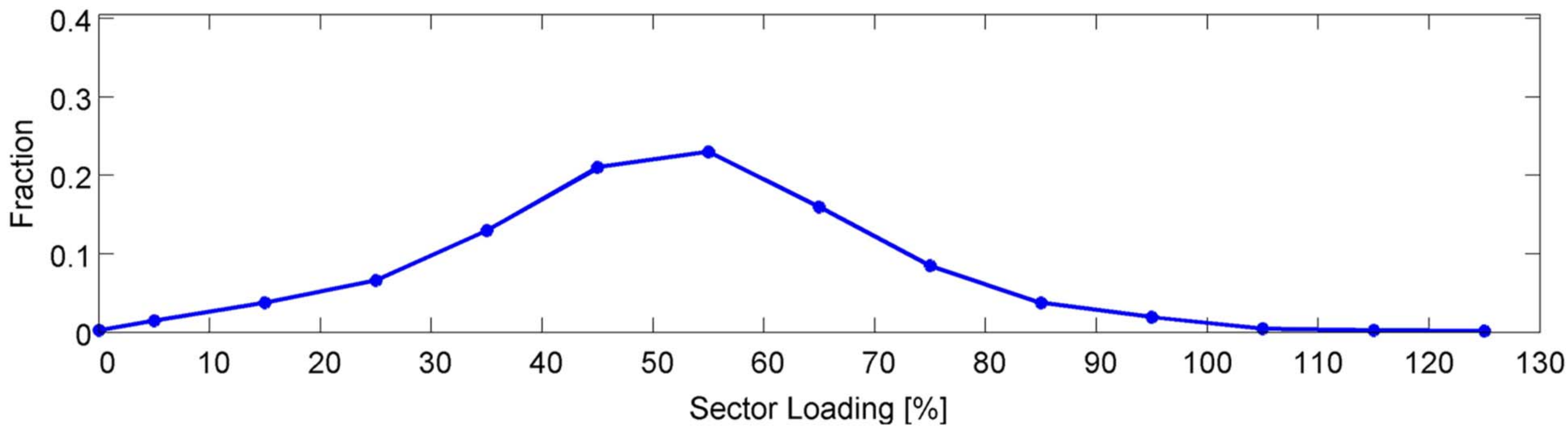
- Aircraft count within a sector is not sufficient for measuring the difficulty of managing the traffic.
- Much research has been done exploring this problem:
  - Complexity metrics (e.g. heading, density, etc.)
  - Human factors



Airspace Metrics: Workload Factors

- With over 50 workload metrics developed in DAC research, the following were suggested by SMEs to be the most important:
  - *Sector Loading*
  - *Predicted Conflicts*
  - *Transitioning Flights*
    - *Climbing + Descending Flights*
    - *Proportion of Simultaneous climbing & descending flight sets*
  - *Flights Near Sector Boundaries*
  - *Vertical Sector Boundary Crossings*
- For every sector:
  - The maximum value of each workload factor for every 15-minute interval is recorded
- ~2000 data points for each factor and each sector

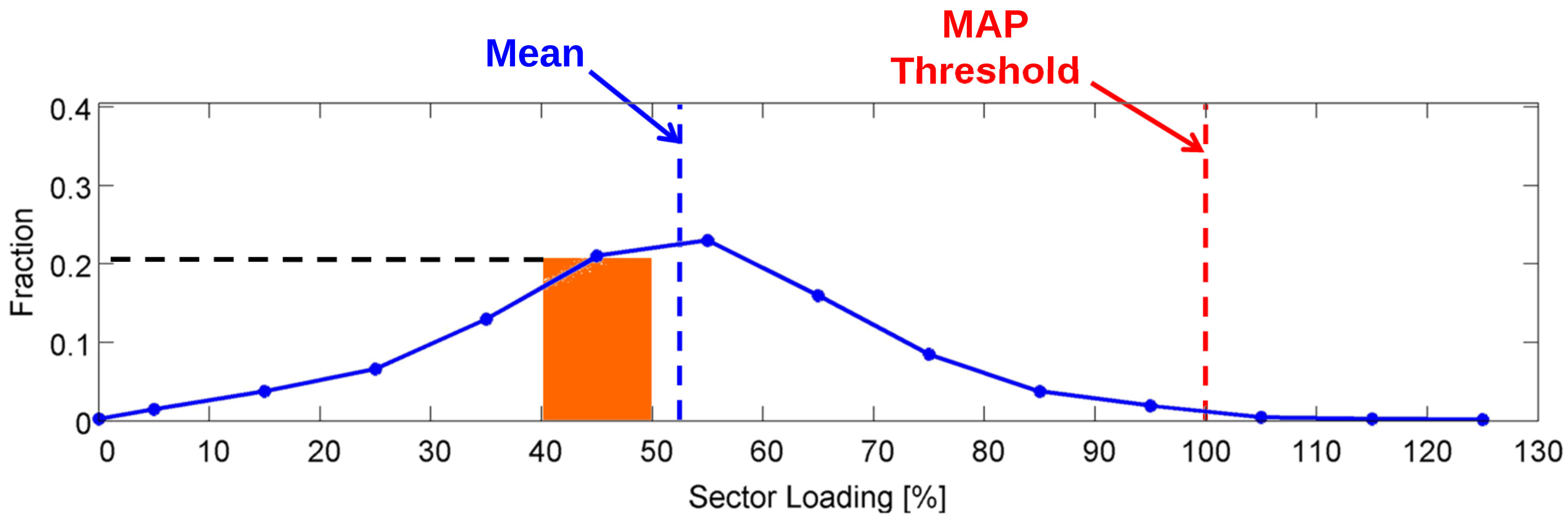
Sector Loading



- *Sector Loading* is computed as: {aircraftCount / MAP}
  - MAP = Monitor Alert Parameter -> a pseudo-capacity value for each sector

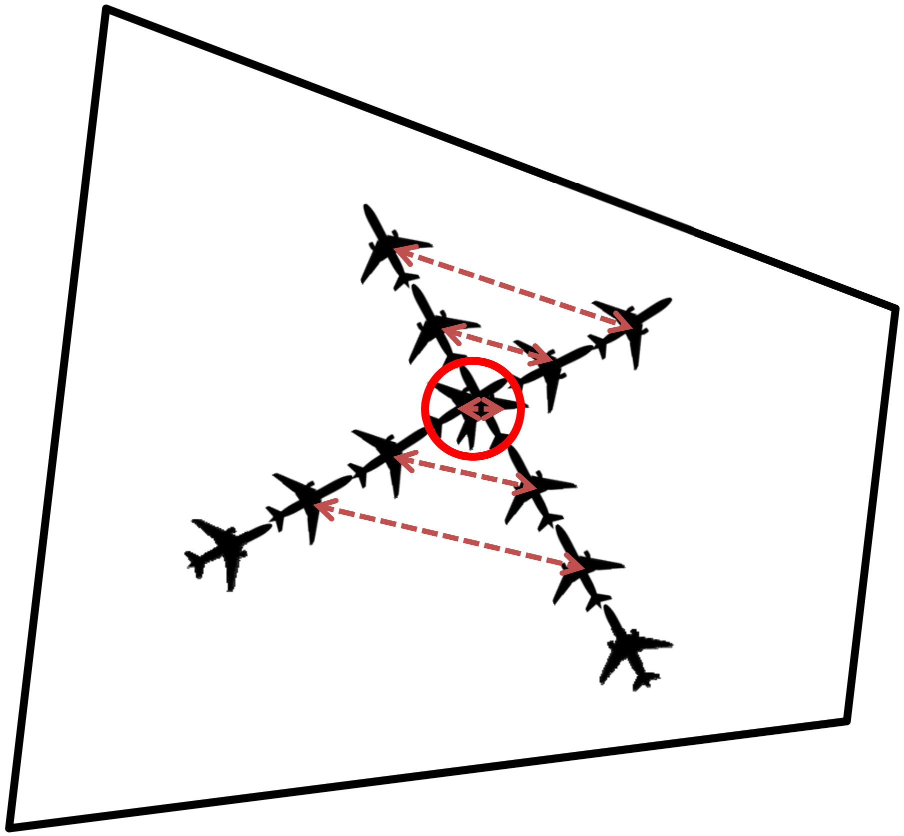
- Distributions of the 2000 data points for every workload factor are plotted and normalized to compare the performance of the scenarios

Sector Loading



- Example: 20% of the time, this sector is between 40% - 50% loaded
- “Good” sector loading performance tends to have median values approx. 25% – 45%
- Over-MAP occurrences are to be avoided

Predicted Conflicts



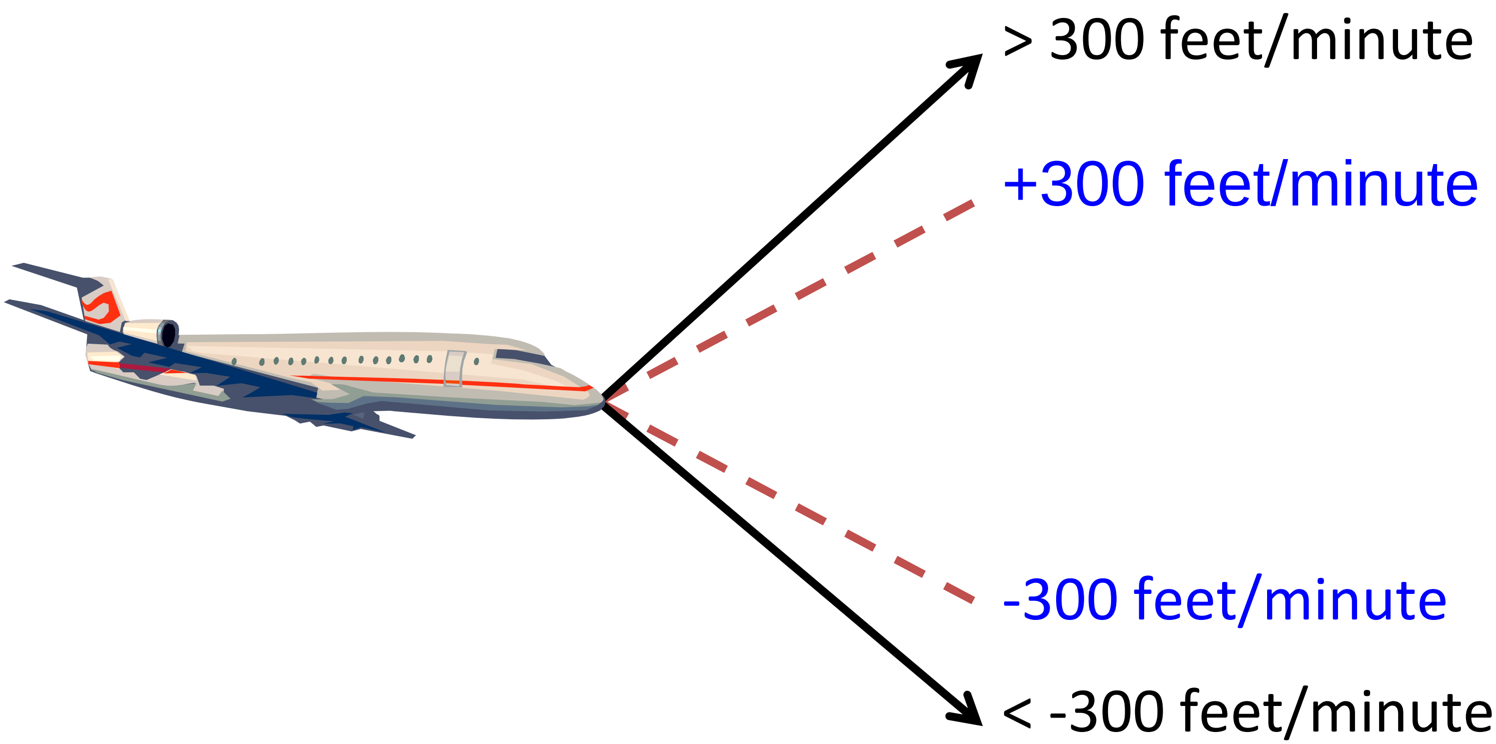
Simulate current flight plan for 15 minutes into the future in 15-second intervals

≤ 8 nautical miles

and

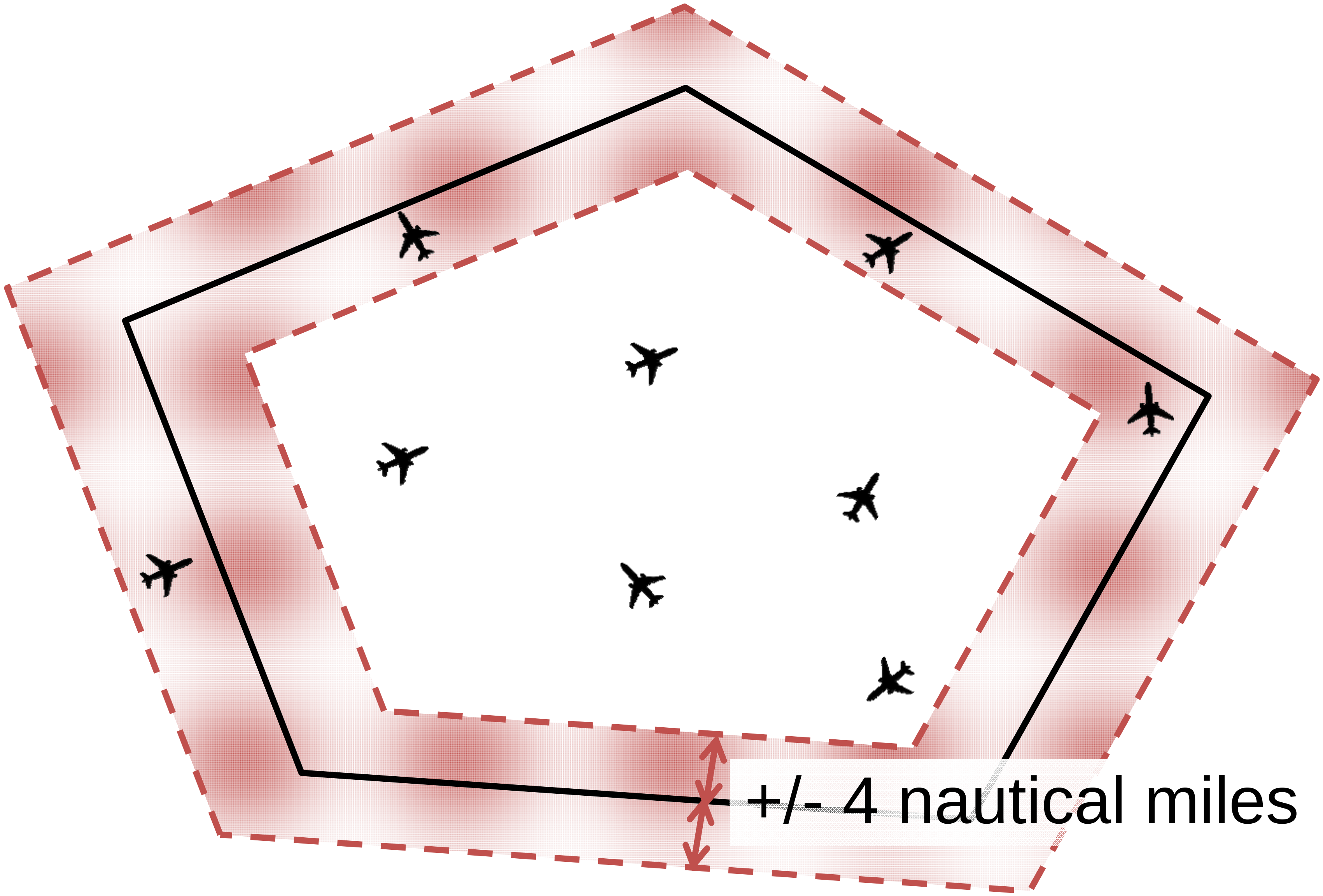
≤ 1000 feet vertical

Transitioning Flights

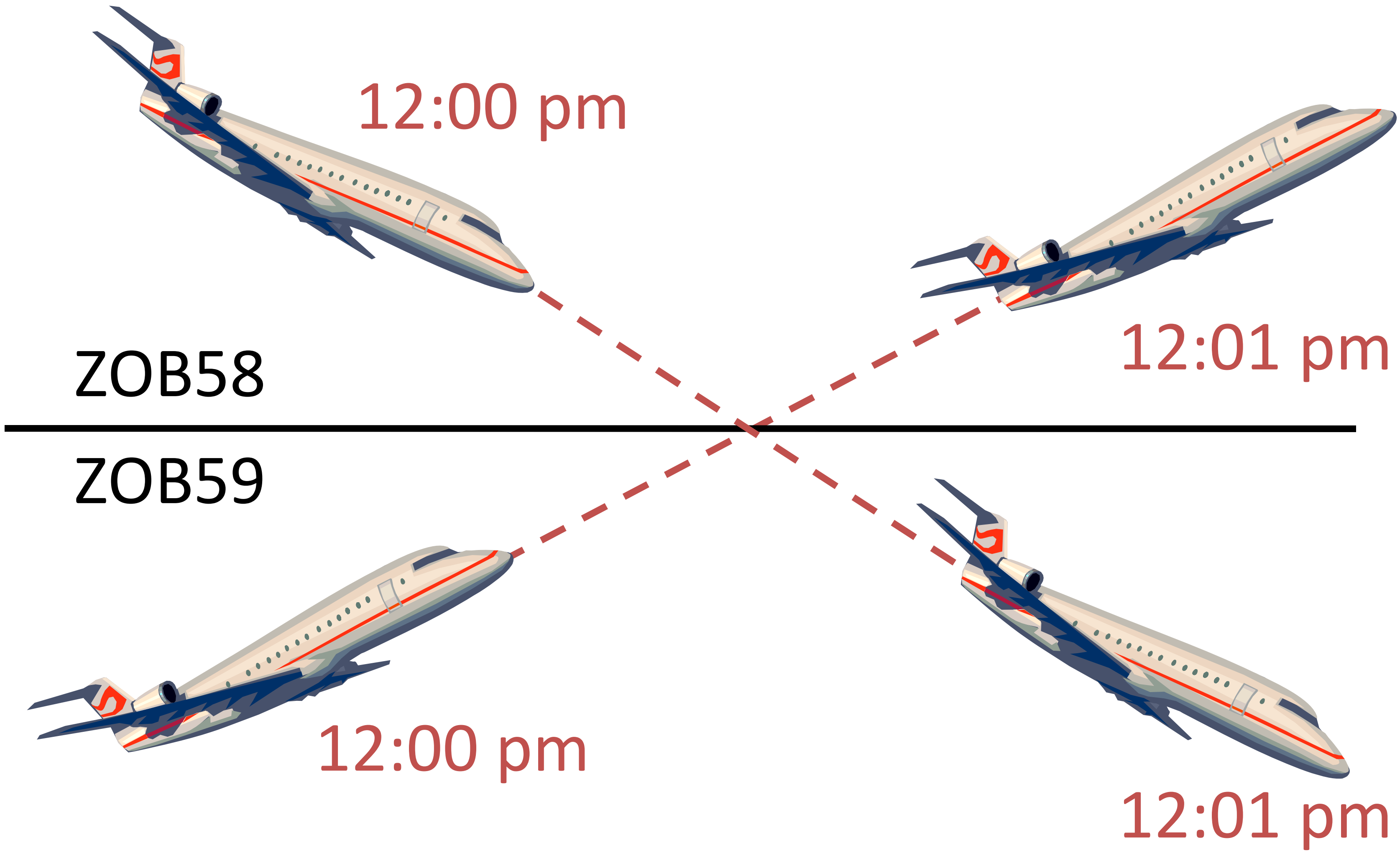


- Two workload factors from this data:
  - Total number of climbing + descending
  - Ratio of simultaneously climbing and descending sets of flights

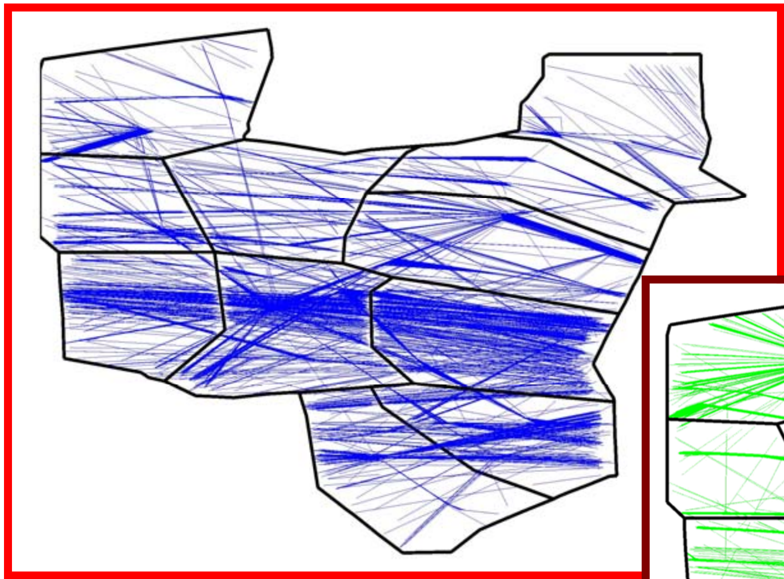
Flights Near Horizontal Sector Boundaries



Vertical Sector Boundary Crossings

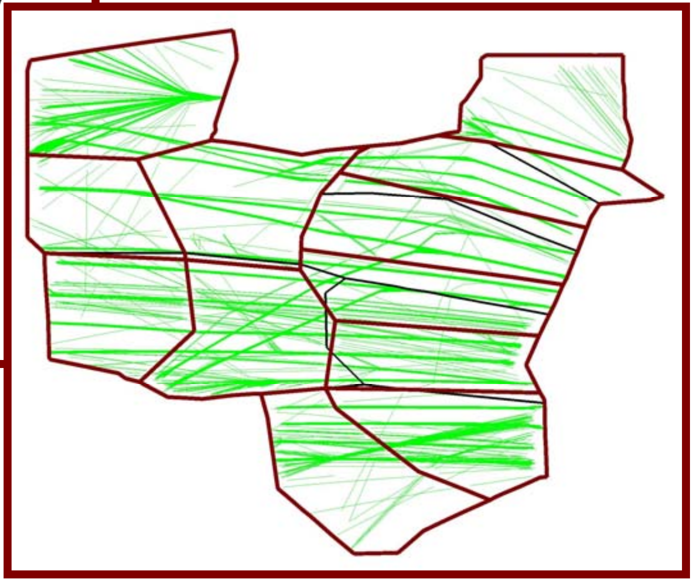


Cleveland Center Routes and Sector Redesign



Scenario A (baseline):
Existing Routes, Existing Sectors

Scenario B:
Proposed Routes, Existing Sectors

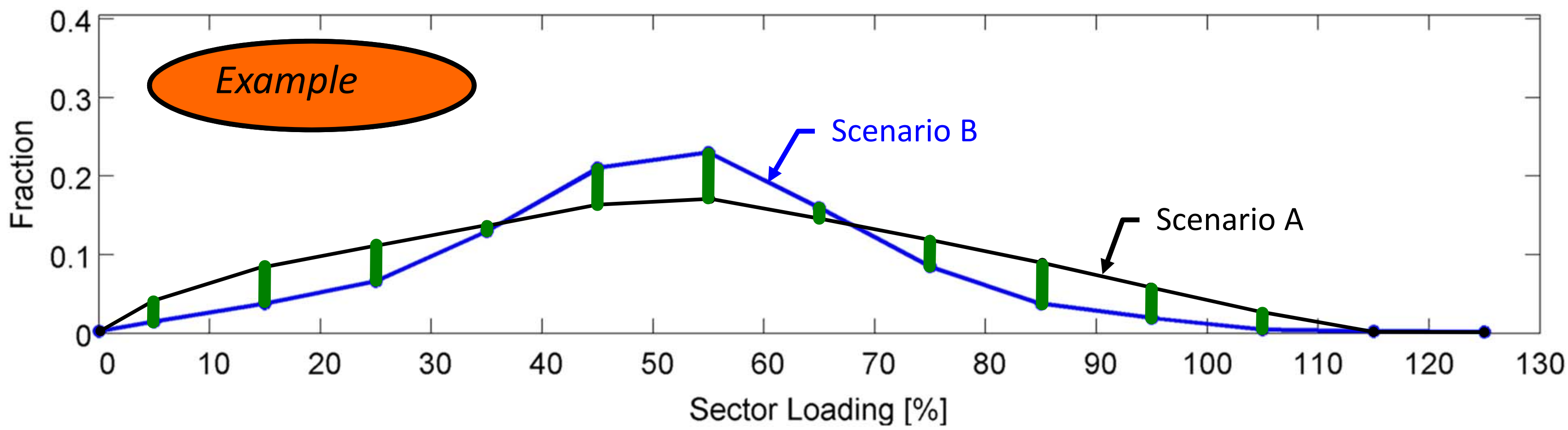


Scenario C:
Proposed Routes, Proposed Sectors

Difference Metric

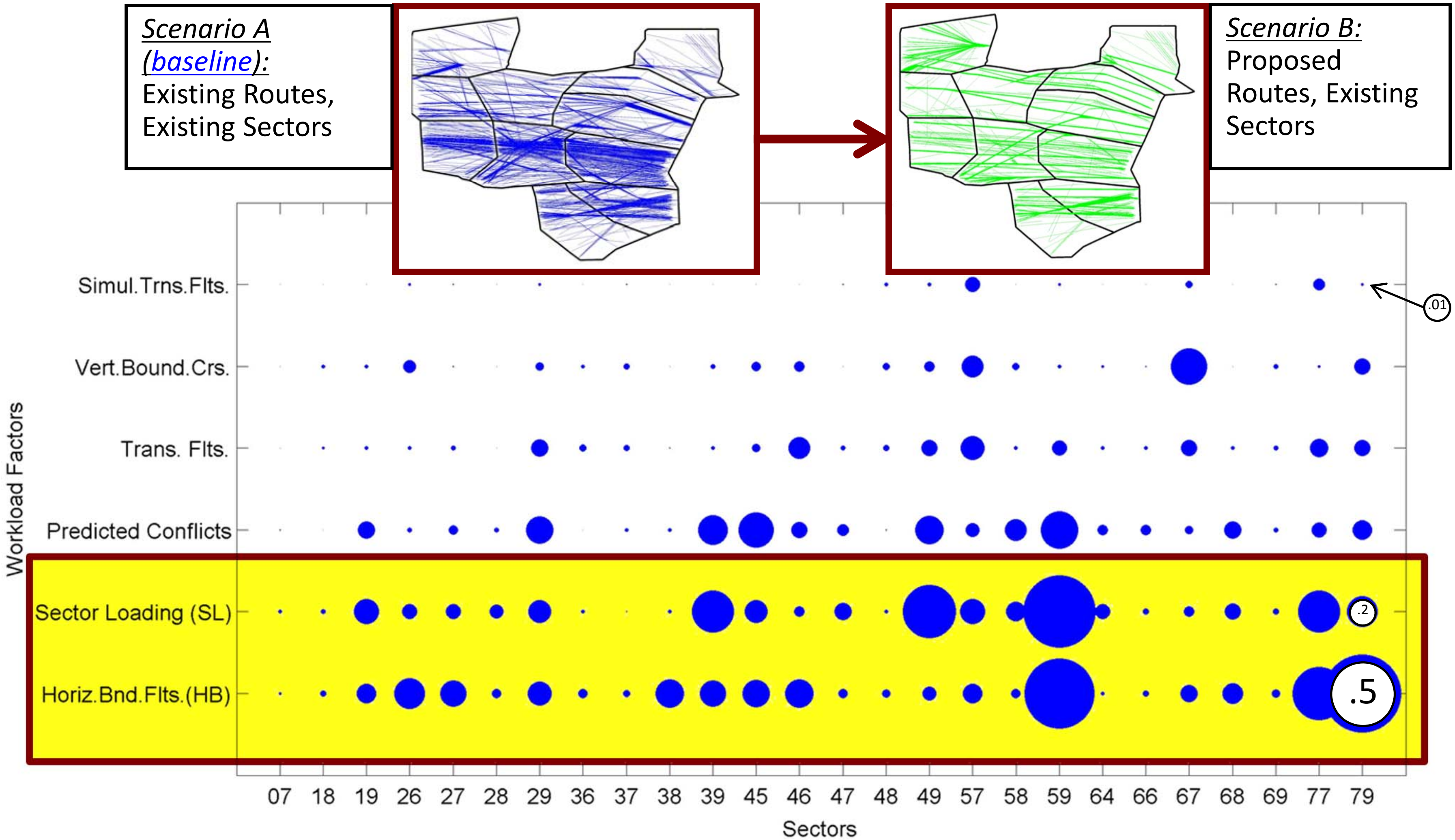
- Identify the *workload factors* and *sectors* that are most affected by the route changes
- For example, the difference between Scenarios A and B for Sector Loading (SL) is calculated as:

$$SL_{A-B} = \sum_i^n |sl_i^A - sl_i^B|$$



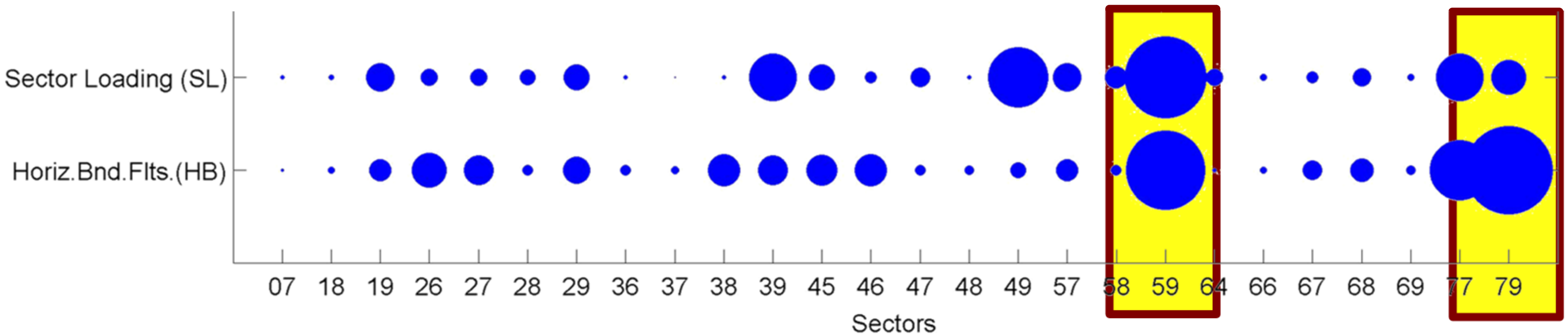
Note that this metric has the range [0, 2] for *all factors*.

Identify the Critical Workload Factors



Sector Loading and flights near Horizontal sector Boundaries are found to be the most affected by the new routes among all *Existing* High and Super-high sectors:

Identify Most Affected Sectors

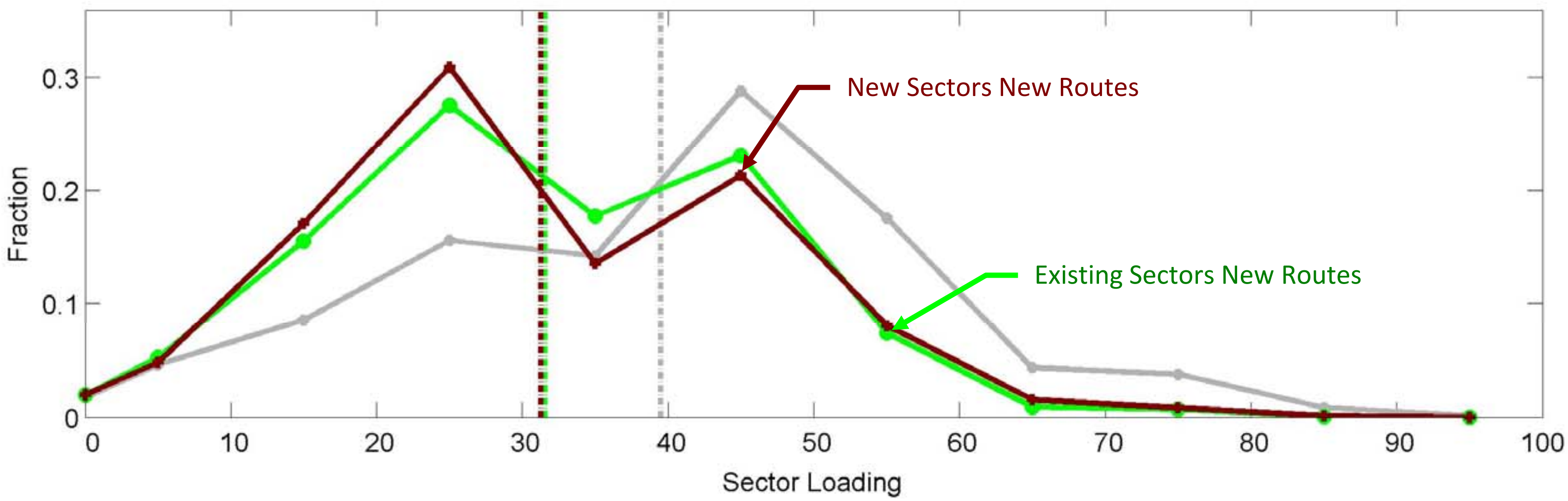


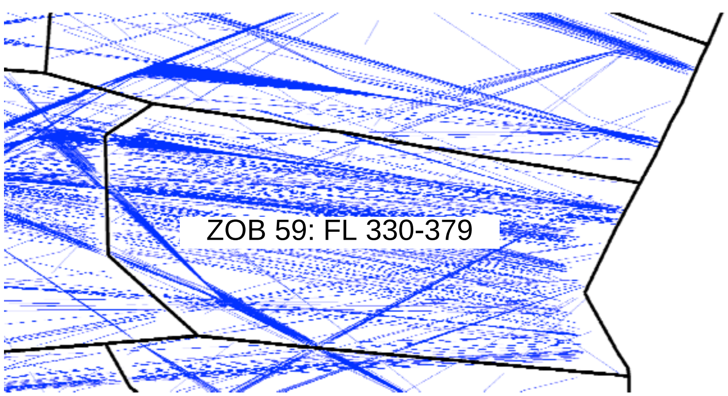
- Many sectors selected for further analysis
- Sectors 59 and 79 presented here

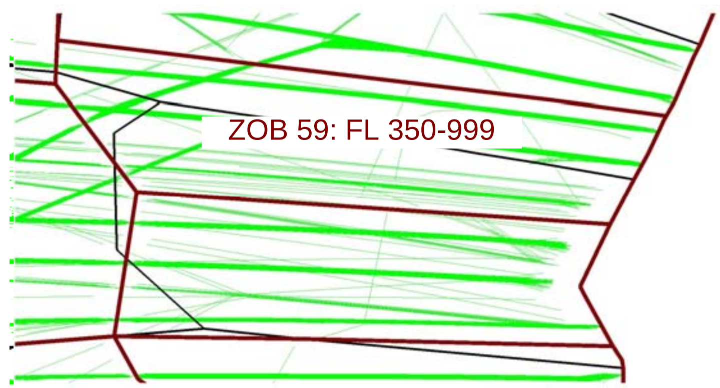
Sector 59: Sector Loading

A -> B: Loading goes down because traffic has been spread out and segregated into distinct lanes.

C: Very little change in SL from B, and lower overall compared to baseline.
The new sector has a smaller footprint, and has been moved to the north, but the floor and ceiling have been raised.



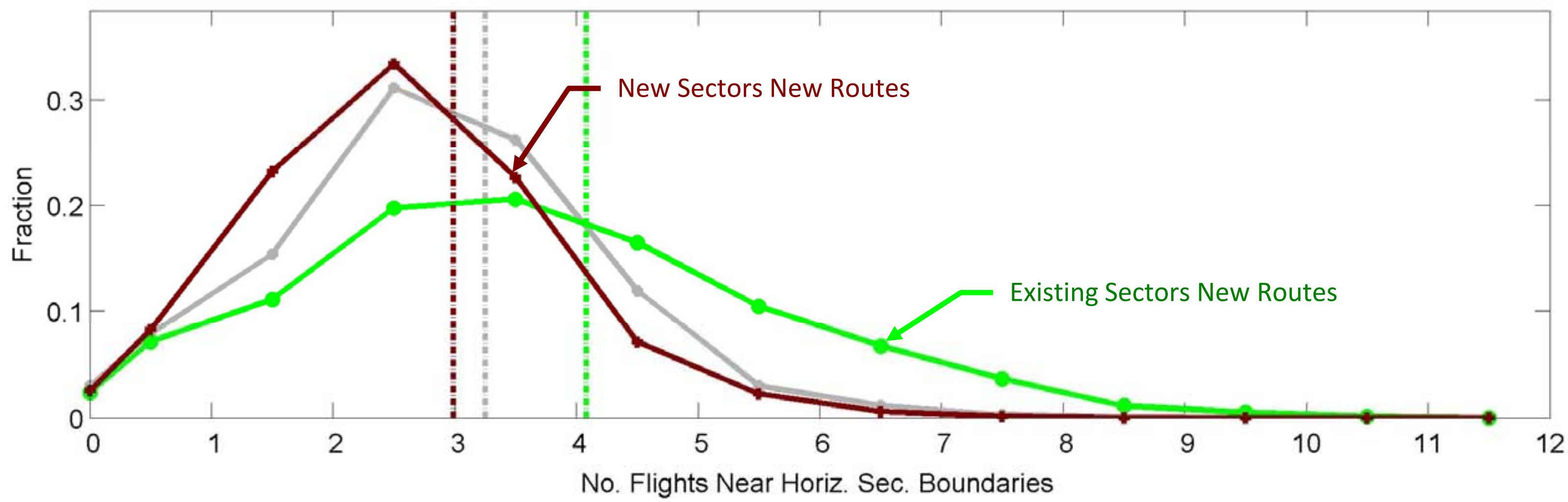


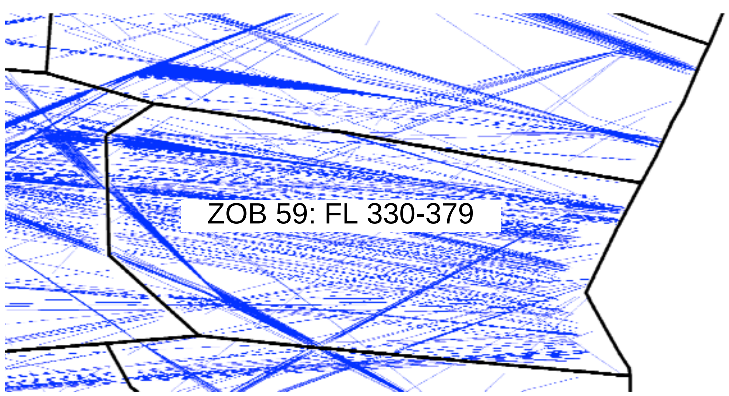


Sector 59: Flts. Near Horiz. Sector Boundaries

A -> B: HB gets worse due to northern boundary route crossing proximity.

C: HB improves (better than in B and A). This is due to boundaries being made parallel to routes and positioned between them.

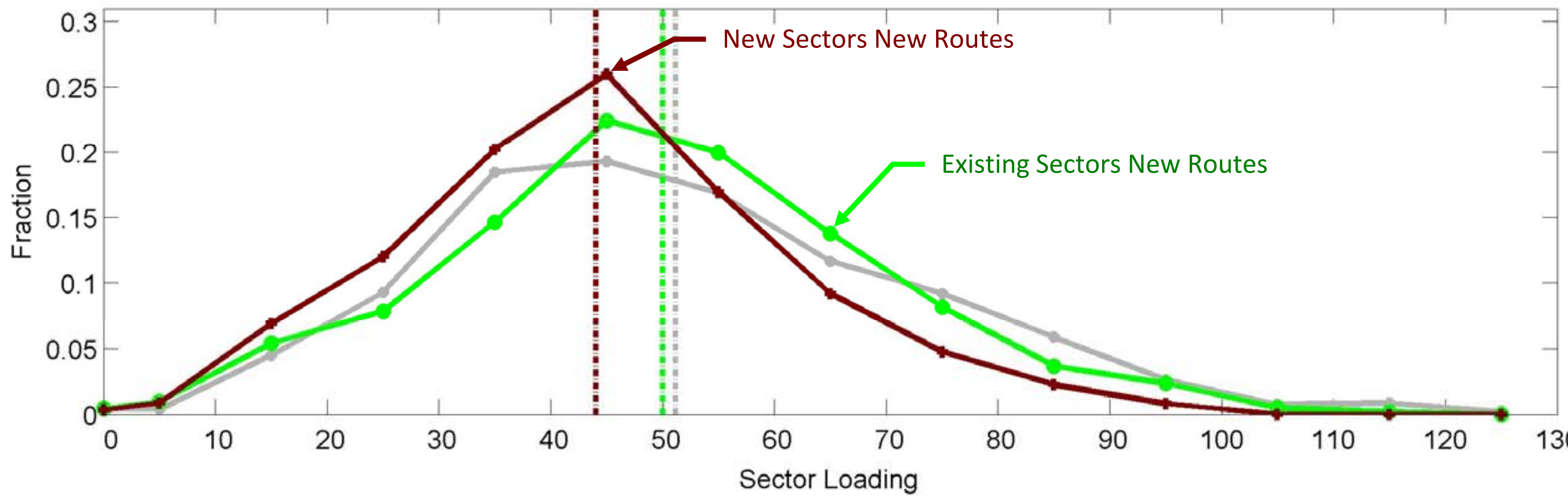


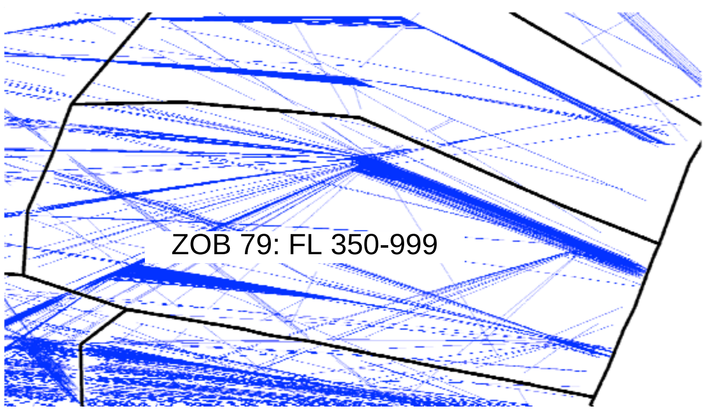


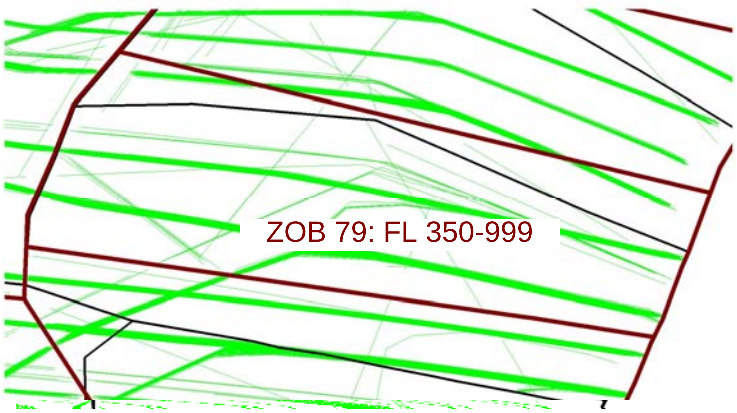
Sector 79: Sector Loading

A-B: Only small change in sector loading.

B->C: Sector loading is reduced in C, better than Scenarios B AND A (baseline).
Significant reduction in loading over 55%, and over-MAP occurrences are reduced.



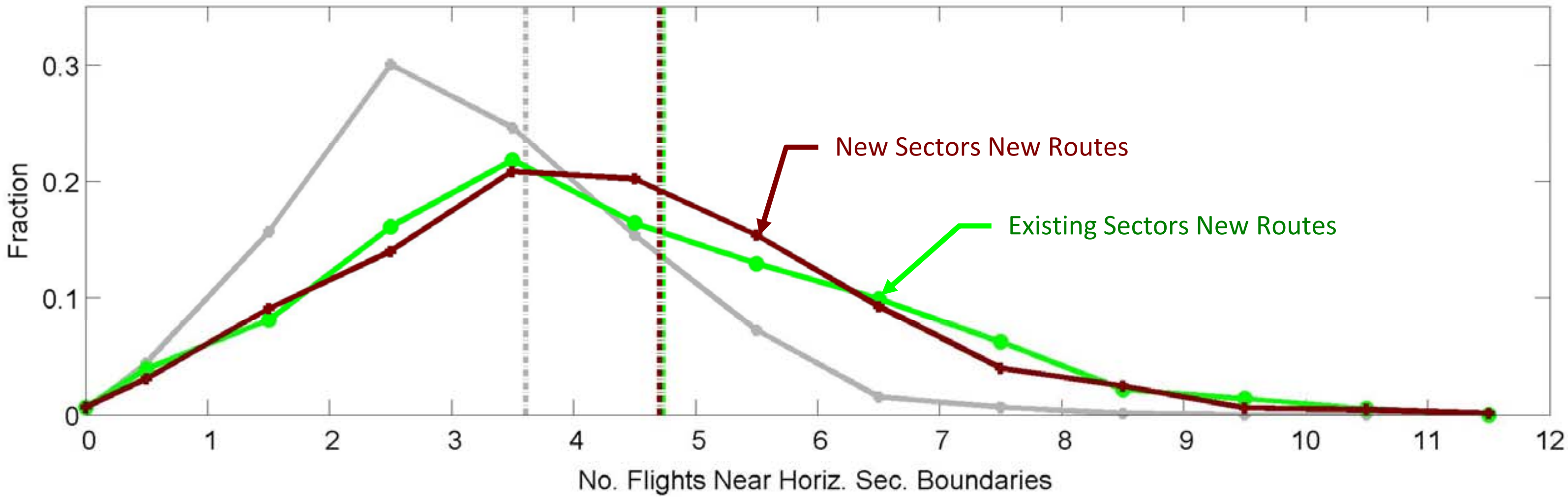


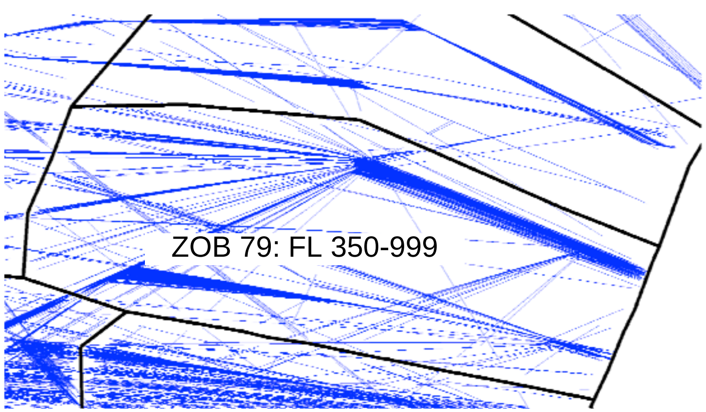


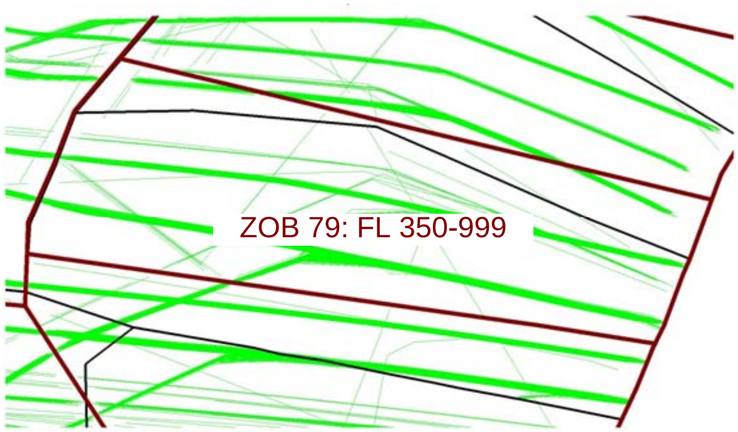
Sector 79: Flts. Near Horiz. Sector Boundaries

A-B: Sector 79 experiences the greatest change of all the sectors in terms of flights near horizontal boundaries.

B->C: The southern crossing route issue is fixed, but a new issue arises on the northern boundary, which is crossed TWICE by Chicago-bound flights. So HB remains as high as it did in Scenario B.







Conclusions

- A methodology was developed to analyze route changes on sector performance
- Applied to proposed route and sector changes in Cleveland Center
- A metric was developed to identify:
  - Controller workload metrics most affected by route changes
  - Sectors most affected
- Sector loading and Flights near horizontal sector boundaries show the most effect when routes are changed
- Most proposed sector changes made to accommodate new routes improve sector performance
- Some potential performance issues identified